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Dish Washer: a Software Tool for RFI Mitigation in Single-dish Radio Astronomical Observations

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Abstract. Radio Frequency Interference is one of the most pressing problems in cm-wavelength world-wide radio astronomy, in particular for single-dish telescope observations. Due to both the increasing abundance of man-made interfering signals and the improved performance of the telescope instrumentation, the impact of RFI at the Italian radio telescope sites is now a major concern, thus strategies for its mitigation are to be applied. Dish Washer is a new software tool for the detection and flagging of RFI in signals collected by single-dish radio telescopes. It implements both interactive flagging and some level of automatic detection of RFI through dedicated algorithms. Its first public release is foreseen as free software under the GNU General Public License.

1. Radio Astronomical Observations and the RFI problem

Astronomers need to observe the Universe in more and more portions of the radio spectrum. However, the frequency bands allocated by the International Communication Union to passive science, even if still fundamental for radio astronomy, are not sufficient anymore to perform cutting-edge science. Radio Frequency Interference (RFI) has thus become one of the most pressing problems in cm-wavelength world-wide radio astronomy, and the situation is ever-deteriorating.

New telecommunication and broadcasting technologies are nowadays commonly used, many in the form of mobile devices. Since their ever-changing locations are impossible to control, they are rapidly affecting observatory operations. In particular, ultra-wideband devices pose problems for passive services, as their digital modulation schemes do not always respect the boundaries of spectrum allocations. Moreover, the number of transmitting devices used by each person is set to increase dramatically in the future, and many of these will rely on dynamic spectrum access.

Single-dish radio observations are the most vulnerable to the effects of RFI, as astronomical and man-made signals are added coherently, in contrast to what happens for interferometers. As a consequence, RFI may easily corrupt single-dish data to the point of preventing their scientific exploitation. Different strategies are thus under development at the various observatories worldwide to realize an effective RFI mitigation system, ranging from hardware solutions for data acquisition and real-time processing to offline techniques for RFI detection and excision to be used in the post-acquisition phase.

The impact of RFI has increased enormously at the Italian telescope sites recently, not only due to its abundance and increasing appearance at higher frequencies, but also because of the more frequent usage of our antennas for single-dish wide-band radio continuum observations. The specific topography at the Italian radio observatory sites, especially the Medicina one,

leads to a full exposure of the antennas within the most densely populated areas in Europe, putting them in a front position to anticipate the evolution of the RFI situation at any other radio observatory site in the near future. This situation motivated the development of Dish Washer (DW), a software tool aimed to allow the offline identification and excision of the RFI affecting single-dish radio telescopes.

2. Dish Washer: package structure and main features

DW is a python package providing tools for detection and flagging of RFI on data collected from single-dish radio telescopes, developed at the Institute of Radioastronomy in the framework of a project of relevant technological interest funded by the Italian National Institute for Astrophysics.

DW is composed of 3 python sub–packages in charge of different functionalities and responsibilities, and a C library aimed at efficient RFI detection algorithm implementation:

- the *dw.gui* sub–package implements the Graphical User Interface which allows us, for instance, to visualize the data, inspect it and manually flag/deflag it. This package does not implement functionalities that affect the data, it uses instead those implemented by *dw.core*
- The *dw.core* sub–package contains the implementation of the core functionalities of the package: main data structure definition, data I/O, command logging, manual flagging, auto flagging algorithm calls.
- The *dw.flag* sub–package provides a framework for the implementation of RFI detection algorithms. It is composed of three main classes to be used to write actual detection algorithms in python or, for the sake of computational efficiency, in C through the *libdw* library.
- The *libdw* library, written in C, provides initialization functions and some basic flagging algorithms. It is the place where new, clever and efficient RFI detection algorithm have to be implemented.

The three sub–packages and the C library are related in a strict hierarchical fashion. With respect to the previous list, from bottom to top, each piece of software can be used alone or can be used by the upper sub–package thus providing an higher level interface. For instance, at the lower lever, the *libdw* library can be linked from any programming language able to link C libraries, if only the provided algorithms are required. The *dw.flag* provides direct access to the *libdw* library from a python application or interactive interfaces (i.e. IPython). The *dw.core* provides full access to all DW capabilities except visualization, again for python application or interactive interfaces, and finally the *dw.gui* sub–package provides the Graphical User Interface for data visualization and inspection. The user can thus select different approaches to use the DW package and possibly include the functionalities in its own software. The structure of DW packages and classes is shown in Figure 1.

The DW GUI permits data inspection including cross sections, contrast adjustment etc. It handles and summarizes the observational metadata that are considered useful for the flagging process, like the observing date and time and the antenna pointing coordinates. Also, the GUI allows the manipulation of the flagging regions by means of tools for their creation and/or visualization and merging, as well as the possibility of deflagging selected areas.

State–of–the–art radio astronomical instrumentation is capable of delivering a huge amount of data in a single observation, due to both the wide spectral band / short integration times and the modern multi–feed receivers currently available. The complexity of the delivered datasets is a major limit for an efficient flagging in terms of processing time. To cope with this aspect, DW has been designed so as to automatize as far as possible the flagging of large spectropolarimetric datasets by including dedicated functionalities for the propagation of the flagging regions within different selected datasets. Also, parallelization of the functions implemented in the C library

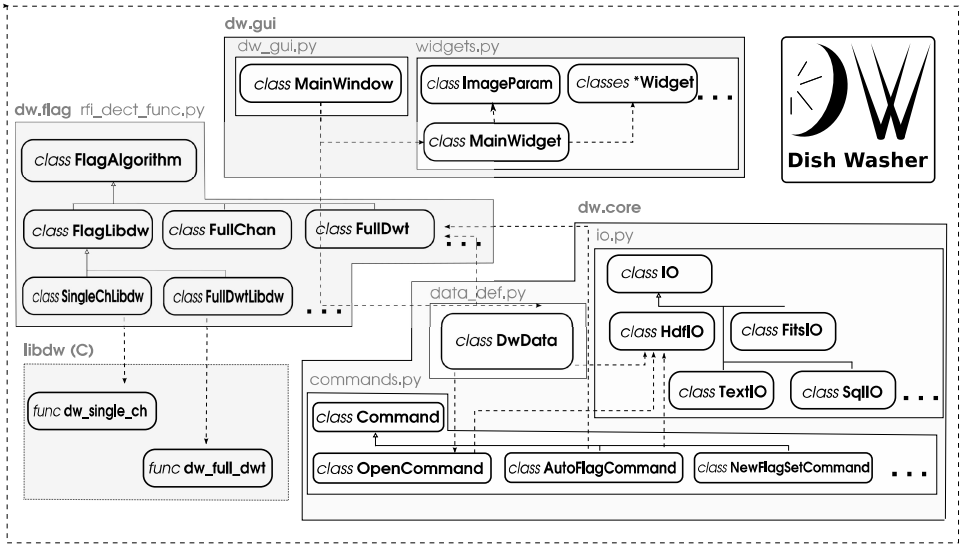

Figure 1. Dish Washer Package and Classes Structure.

using OpenMP directives has been successfully tested, proving the possibility of exploiting today's multi-core/multi-thread processors and efficiently run extremely expensive RFI detection algorithms and/or process large amount of data.

In its current version, DW handles the standard FITS data format in use at the three single-dish Italian radio telescopes and implements the possibility of manual interactive flagging plus some level of automatic RFI detection through dedicated algorithms. The result of a flagging operation is composed of a set of coordinates describing the region(s) to be masked in the raw data, plus a number of metadata describing the applied method and its relevant parameters as well as the data to which that flagging result is to be applied (e.g. spectral section, feed number, etc.) within the considered dataset. Flagged regions are saved in a FITS extension table appended to the original files, for subsequent use during the data processing operations.

The underlying philosophy in the DW software structure design was to make this tool as flexible, re-usable and expandable as possible, in particular in terms of the possibility to support different input data formats and to implement new RFI excision methods. Support for data formats other than the one in use at the Italian radio telescopes can be easily provided by adding appropriate software modules in the *dw.core* sub–package.In principle, I/O classes can be implemented for any kind of storage format, including text files, SQL DBMS, HDF5 and so on. Easy integration of new RFI detection algorithms, developed both in Python and C programming languages, is possible by exploiting the available features in the *dw.flag* sub–package.

The first public release of Dish Washer is foreseen as free software under the GNU General Public License version 3 (or later).